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Statement of Translation Accuracy

This is to certify that the attached document, *French Patent Application No. 99 05528, including the description and claims,* originally written in French are, to the best of our knowledge and belief, true, accurate and complete translations into English.

Dated: April 22, 2005

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Sworn to and signed before
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2 APPLICATION Nature of the intellectual property title
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LASER WITH EXTENDED OPERATING-TEMPERATURE RANGE

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LASER WITH EXTENDED OPERATING-TEMPERATURE RANGE

DESCRIPTION

Technical Domain

The invention is in the domain of quantum-well lasers including a means of reflection outside the laser's cavity.

Technology Background

A laser is known, for example, from patent US-A-5,715,263 granted to SDL, shown in Figure 2 of this patent, that includes a quantum well laser 26 having an exit mirror 27 and supplying an optical fiber 32. Such a laser is used in telecommunications to pump an amplifier powering a transmission line. According to the invention described in the SDL patent, the fiber 32 includes a Bragg network on fiber 34, having the function of reflecting a part of the light emitted by the laser 26 back towards the laser 26. In this patent (column 2, lines 37 to 45) it is explained that, if the center of the reflection band of the fiber's Bragg network is in the laser's gain band, then that affects the optical spectrum of the emitting laser diode. The exact effect depends on parameters such as the value of the coefficient of reflection of the fiber's Bragg network, its bandwidth, the network's central wavelength compared to the laser, the value of the optical distance between the laser and the network, and the value of the laser's injection current. In the SDL patent

the Bragg network's central wavelength is contained inside a 10 nm band around the laser's wavelength and the network's 34 coefficient of reflection has a value similar to that of the exit facet 27 of the laser 26. In the preferred embodiment the bandwidth reflected by the network 34 and its coefficient of reflection are such that the return into the laser cavity due to the exit facet is greater than the return due to the network 34. That way the network 34 acts as a perturbation of the emission spectrum of the laser diode 26, which has the effect of broadening the emission band and thereby making the diode less sensitive to perturbations due to temperature or injection current changes.

To obtain the desired effect, in the preferred embodiment, the network 34 has a reflection peak located 1 or 2 nm from the diode's wavelength, a 3% coefficient of reflection, which considering the coupling between the network and the diode leads to a return coefficient towards the diode of 1.08%.

From the patent US-A-5,563,732 granted to AT&T Corp., a pumping laser 13 for laser amplifier 12, also used for optical transmission, is also known. This laser 12 is stabilized to avoid fluctuations in the emitted wavelength caused by parasitic reflections coming from the laser amplifier 12 by using a fiber network 14. The inventors establish that the pumping laser 13 is stabilized if the coefficient of reflection of the network 14 is between 5 and 43 dB.

The experiments conducted by the applicants have shown that the use of lasers stabilized by means of a fiber network could effectively have a good influence on the laser's operating stability and, in particular, on the stability of the emitted wavelength, although within certain limits. In particular, the use of lasers stabilized in the manner described in each of the two patents cited above does not make it possible to obtain a laser that could operate in a temperature range extending from -20°C to +70°C, as is currently required by most users. Therefore, the need for such a laser exists.

Brief Description of the Invention

The invention targets a quantum well laser like those described in the two aforementioned documents, but which is capable of operating without specific precautions in a temperature range between two limit temperatures about 100° apart, in particular in the temperature range between -20°C and +70°C. First of all, it is important to understand that operating between -20°C and +70°C is not the same thing as broadening the operating band in order to have an output wavelength independent of reasonable fluctuations in the operating temperature, for example, in a temperature range fluctuating 5 or 6° around a nominal operating temperature.

As in the prior art, the invention uses a quantum well laser formed by a laser medium between a mirror facet and an exit facet having a coefficient of reflection

- means of coupling the laser exit to an optical fiber
- the optical fiber having a fiber network returning a fraction of the light received from the laser by the fiber back towards the laser cavity through the intermediary of coupling mechanisms.

All the same, an important characteristic makes the invention different from the prior art. The inventors have observed that, at a given temperature, the cavity's gain curve as a function of wavelength has, going in the direction of increasing wavelength, a positive slope, a maximum at wavelength λ_{max} and then a negative slope. The positive slope is much smaller than the slope which follows the maximum. By observing the way in which the gain curve changes as a function of temperature, they have noted that, for example, for a laser operating at 980 nm at 25°C the maximum moves from 966 nm at -20°C to about 995 nm at 70°C The movement is nearly linear with a coefficient of about 0.3 nm per degree. In order for the system to operate over a large temperature range, it is necessary that, over the entire temperature range, the condition under which the cavity's gain is equal to the cavity's losses hold true for the wavelength

of the fiber's Bragg network, despite the changes to the cavity's gain curve as a function of wavelength brought about by the temperature variations. For this latter condition to be fulfilled, the inventors have found that it is sufficient that, at the median temperature of the operating range, the reflection wavelength of the fiber's network have a value which is at least 10 nm below the value of the wavelength λ_{max} at which the cavity has a maximum gain. In practice the difference needed is 15, plus or minus 5 nm. Placement at a wavelength value located about 15 nm before this maximum makes it possible for a large range of temperatures to satisfy the threshold condition under which the gain is equal to the losses at the network's wavelength.

In summary, the invention relates to an optical device comprising:

- a quantum well laser having a laser cavity formed by a laser medium between a mirror facet and an exit facet returning part of the light energy towards the cavity, the cavity having a gain curve as a function of wavelength showing for increasing wavelength a positive slope, a maximum for a wavelength λ_{max} and then a negative slope,
- means of coupling the laser output to an optical fiber, the optical fiber having a fiber network defining a peak coefficient of reflection for a wavelength λ and returning towards the laser cavity

through the means of coupling a fraction of the light received from the laser by the fiber

- device characterized in that the value of the wavelength λ defining the peak reflection of the fiber's Bragg network is at least 10 nm less than the value of the wavelength λ_{max}.

Preferably the energy received by the laser cavity returning from the on fiber network is greater than the energy received returning from the laser's exit facet.

This functional characterization can be made precise by a structural characterization defining a ratio linking the laser's exit facet coefficients and the network's coefficient of reflection. The product of the fiber network's coefficient of reflection and the square of the coefficient of loss due to coupling between the fiber and the laser must be greater than the coefficient of reflection at the cavity's exit facet. In this way the energy received returning from the fiber network can no longer be considered as a perturbation enlarging the exit optical spectrum. The value of the wavelength reflected by the network determines the value of the laser's exit wavelength. In a known manner, the value of the wavelength λ reflected by the fiber network varies much less with temperature than the cavity does. It follows from this that with this configuration, the optical system made up of the laser, fiber and coupling mechanisms is capable of operating while depending less

on local temperature variations. In an embodiment of the invention, the value of the network's coefficient of reflection is more than 10 times greater than the coefficient of reflection of the laser's exit facet.

Brief Description of the Drawings

An example of embodiment of the invention will now be discussed and explained with the help of the attached drawings in which:

– Figure 1 is a schematic representation of an embodiment of the invention.

– Figure 2 is a set of three pairs of curves, each pair representing the laser cavities gain and losses respectively. The pair of curves A represents the laser cavity's gain and losses at 25°C, the pair of curves B at 70°C, and the pair of curves C at -25°C.

Description and Commentaries on an Embodiment

Figure 1 represents schematically a well-known laser cavity 1 placed so that the emitted laser beam is directed by means of optical focusing 2, and an optical fiber 5, including in a known manner a fiber network 6. The laser 1 can in a known manner described, for example, in the patent US-A-5,715,263 already cited, be made up of a diode laser consisting of an epitaxial quantum well structure or even an InGaAs semiconductor medium arranged with a reflecting mirror 8 and an exit facet 9 having a very low coefficient of reflection,

compared to that of the mirror 8. The laser cavity is formed between the mirrors 8 and 9.

The well-known optical focusing means are comprised of a first collimation lens 3 followed by a focusing lens 4 that focuses the light towards the center of the fiber 5.

The characteristic features of the invention are now explained and commented on in connection with the curves from Figure 2. Part A of the figure represents the laser cavity's gain curve 10 as a function of wavelength and the curve 11 represents the losses of this same cavity as a function of wavelength. The laser can only function to the extent that the losses are less than the gain. In the case of the device represented in Figure 1, the respective values of the coefficients of reflection from the cavity's exit facet 9 and the network 6 are such that this only occurs for the wavelength λ, which is the reflection wavelength of network 6. This is due to the fact that the light reflected by the network is greater than the quantity of light reflected by the exit facet 9. In the case shown in Figure 1, the value of the coefficient of reflection for the exit facet 9 is typically 0.1%, whereas the value of the coefficient of reflection from the network 6 is typically of order of percent while remaining less than or equal to 5%. With this manner of choosing the relative values of the coefficients of reflection, the laser's emission frequency inside the range authorized by the medium is

determined by the network's reflection wavelength. As explained above, the result of this is great operating stability. The changes in the curves 10 and 11 when the temperature varies are of interest. The curves from part A are representative of operation at 25°C. The same curves 10 and 11 have been shown in parts B and C of Figure 2 for temperature values of +70°C and -20°C, respectively. First of all, we observe that the curve 11 representing the losses undergoes practically no change, and most of the value of λ is slightly displaced. The gain curve 10 shows a small positive slope for small wavelength values, then a maximum, and finally a steep negative slope. This is confirmed for the three temperatures shown. It can be seen that for increasing temperatures the maximum shifts relatively significantly towards increasing values of wavelength, and that the maximum increases with temperature so that the length of the line with the positive slope increases. The inventors have chosen a value for the reflection wavelength λ of network 6, at the median of the desired range of operating temperature, about 13 nm below the wavelength of the gain curve's 10 maximum at the same temperature. In the present case, the desired operating range is from -20°C to +70°C. The median temperature of the range is therefore 25°C. With this choice, as shown in part B, there still exists at the high end of the temperature range,

a possible and stable operating point at this temperature for the reflection wavelength λ of network 6. Similarly at -20°C, at the low end of the temperature range, there again exists an operating point; here, as shown in part C of Figure 2, the maximum of the curve 10 is located at a wavelength value that is near the reflection wavelength λ of network 6 at this temperature. Thus, the laser operates properly in the desired temperature range.

The laser according to the invention can naturally be used for the same purposes as those described in the prior art cited, and notably comprising pumping a power laser constituted by an erbium doped fiber.

CLAIMS

1. Optical device including:

- a quantum well laser having a laser cavity formed by a laser medium between a mirror facet (8) and an exit facet (9) returning part of the light energy towards the cavity, the cavity having a gain curve as a function of wavelength showing for increasing wavelength a positive slope, a maximum for a wavelength λ_{max} and then a negative slope
- means of coupling (2, 3 and 4) the laser exit to an optical fiber (5), the optical fiber having a fiber network (6) defining a peak coefficient of reflection for a wavelength λ and resending towards the laser cavity, by means of coupling (2, 3 and 4), a fraction of the light energy received by the fiber from the laser
- device characterized in that the value of the wavelength λ defining the peak reflection of the fiber's Bragg network is at least 10 nm less than the value of the wavelength λ_{max}.

2. Optical device according to Claim 1, wherein the value of the wavelength λ defining the peak reflection of the fiber's Bragg network is at least 15, plus or minus 5 nm, less than the value of the wavelength λ_{max}.

3. Optical device according to Claim 1 or 2, wherein the value of the coefficient of reflection of the network 6 is more than 10 times greater

than the coefficient of reflection of the laser's exit facet (9).

4. Optical device according to one of Claims 1 to 3, wherein the wavelength λ_{max} is a wavelength which has a value about 13 nm more than the value of the wavelength λ for which the network (6) shows a peak reflection when the operating temperature has a value equal to 25°C.

[see original for Figure 1 and 2]